# Simulating and Analysing Crystal Channelling in the Large Hadron Collider

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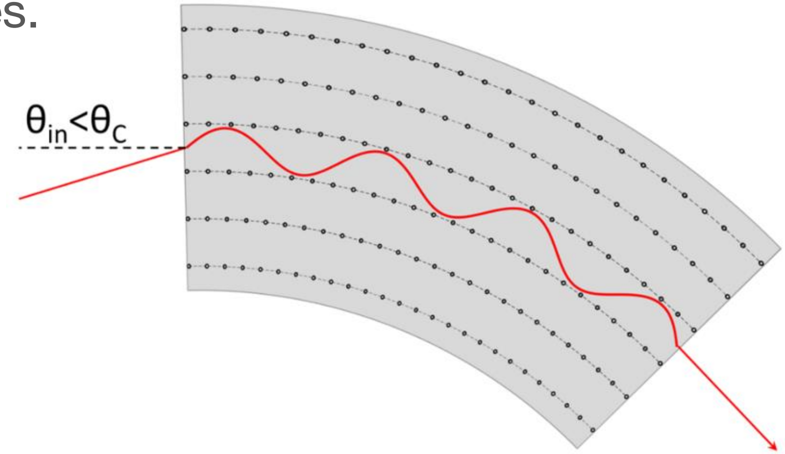
# What is Crystal Collimation?

- A type of advanced **beam cleaning** that uses bent silicon crystals to steer beam halo particles toward an absorber

- When charged particles interact with a crystal at the right impact conditions, they become trapped and **oscillate in the potential well** generated by neighboring crystalline planes.

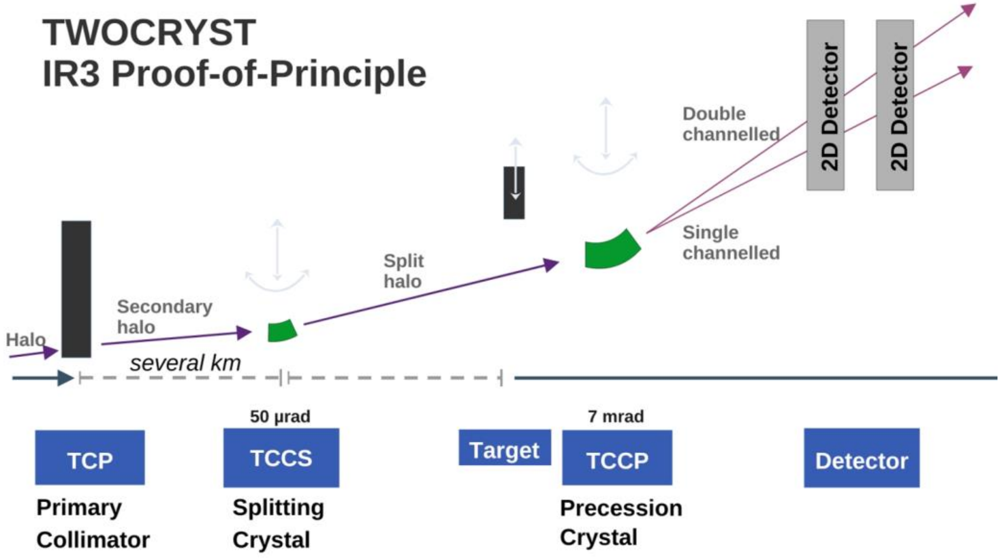
- This phenomenon is called “**channeling.**”



# What is Crystal Collimation?

The Non-linear Dynamics and Collimation (NDC) section uses bent silicon crystals to channel beam halo particles in the Large Hadron Collider

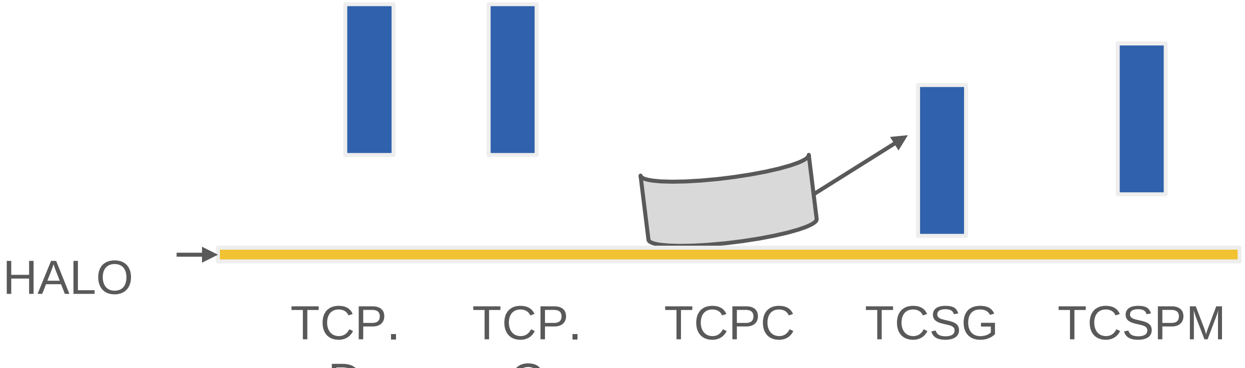
- Particularly useful for **channeling lead ion beams**–the crystal applies the same steering angle for intact lead ions and fragments.
    - This is why crystal collimation is being implemented for the **High Luminosity-LHC** project to improve the ion collimation cleaning efficiency!



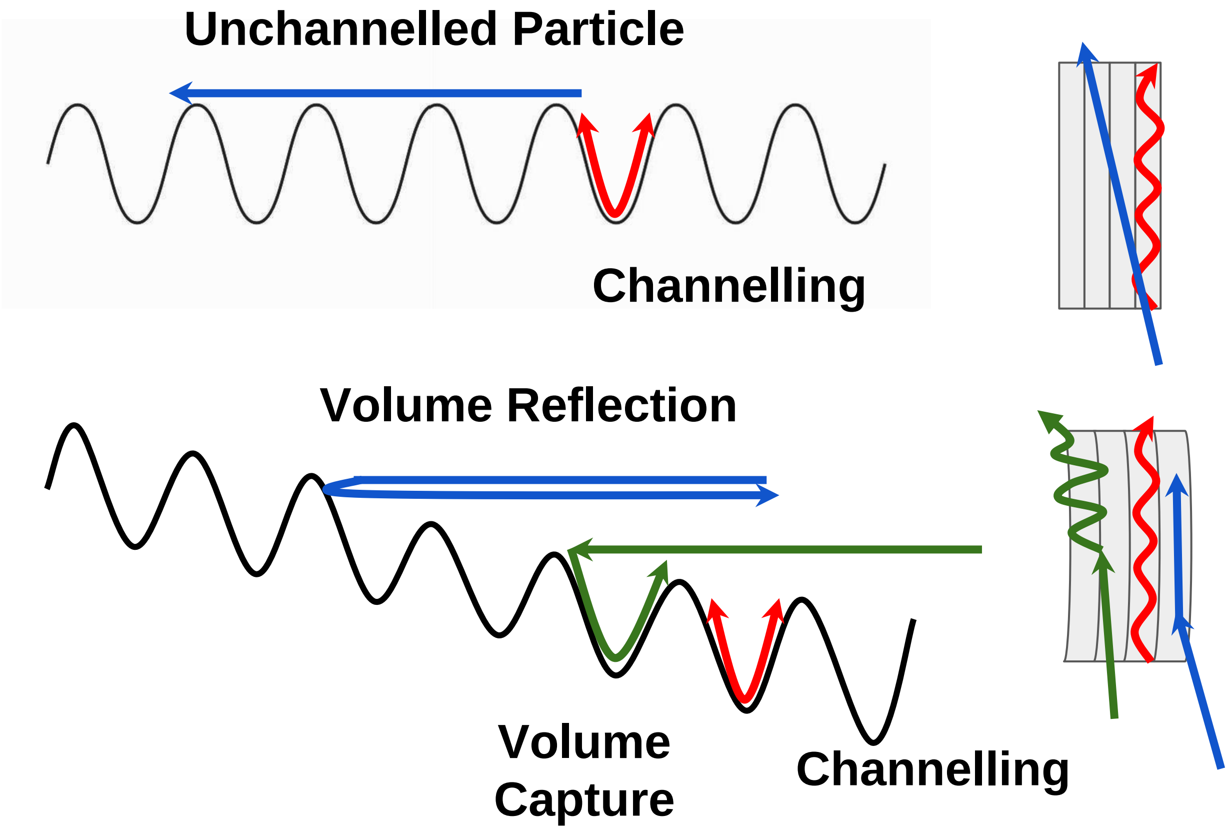
# What I am doing: a change since the first talk!

- For my project, I am using the simulation program **SixTrack** to simulate the results of a recent **Machine Development (MD)** study in the LHC from May 15th, 2024, which focused on testing and arrangement of the collimator/crystal hierarchy.

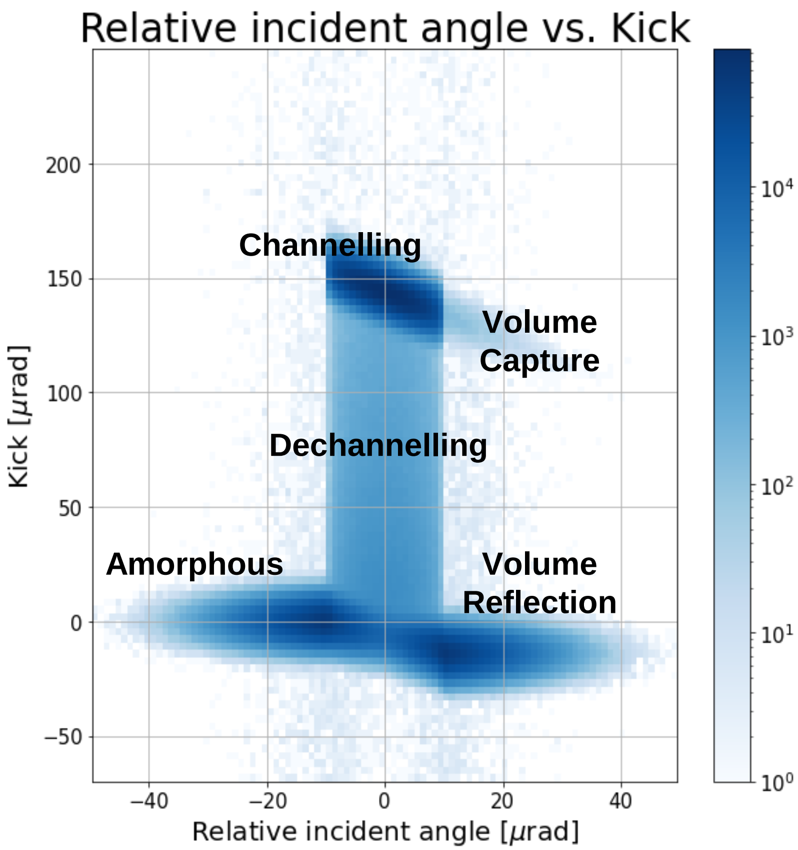
**First step: develop and test an analysis algorithm, which calculates the channeling efficiency, or the percent of particles channeled by the crystal.**



# Phenomena from Crystal Particle Interactions

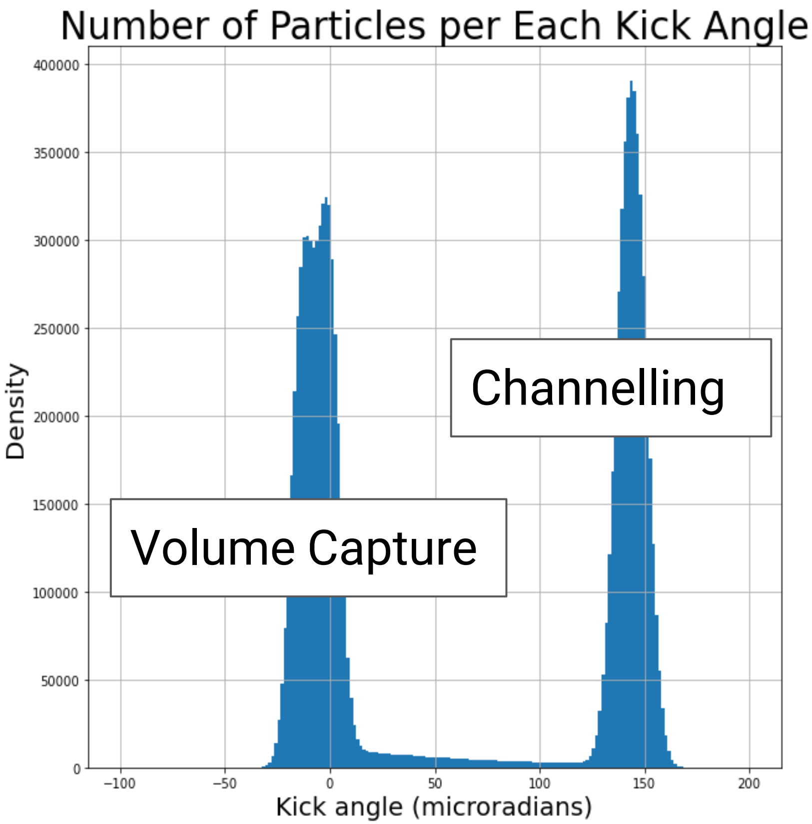


# Recognizing Phenomena



# Finding the Channelling Efficiency

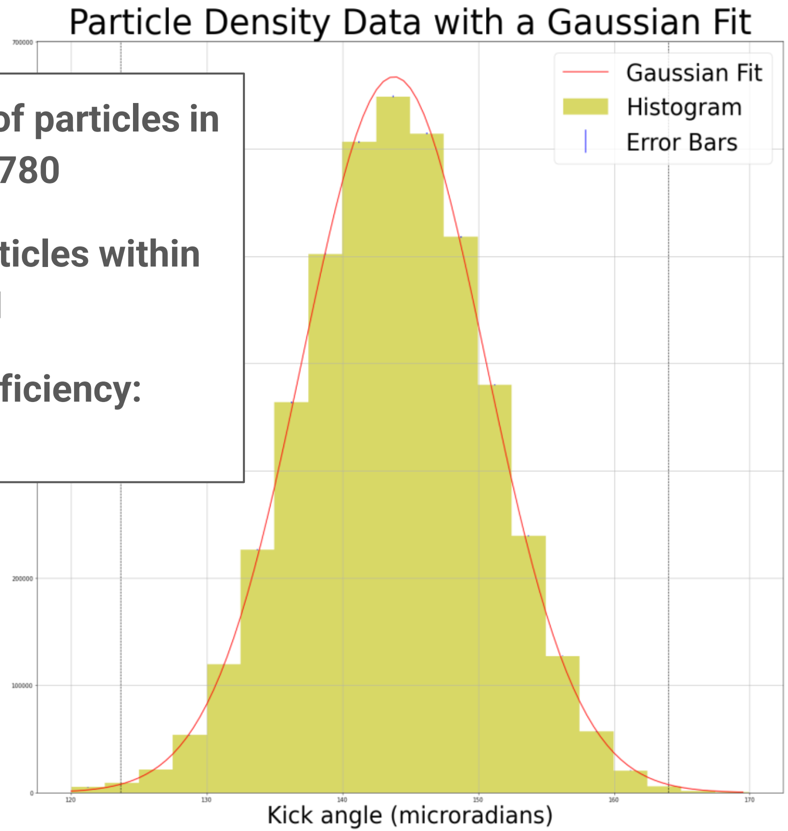
±10 µrad cut on the proton incident angle is applied




**Total number of particles in the cut: 6,824,780**

**Number of particles within ±3σ: 4,509,501**

**Channelling Efficiency: 66.1%**



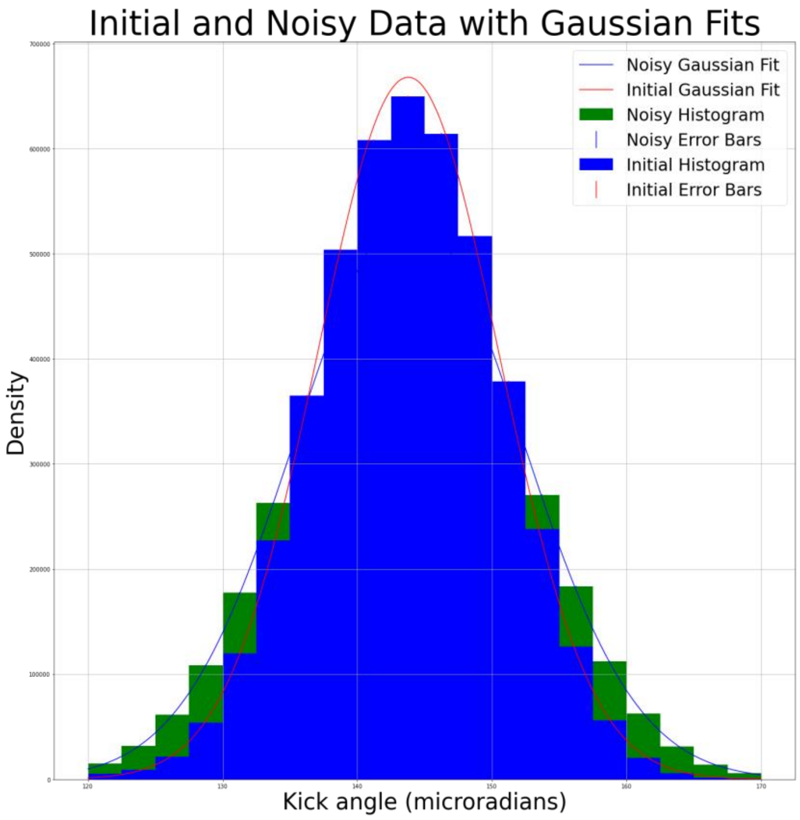
# Including Resolution

- I added an **experimental resolution** by adding random gaussian noise to the simulated deflections at the same level that noise occurs in the experiment.
- You can see the added resolution in green!

**Total number of particles in the cut: 6,824,780**

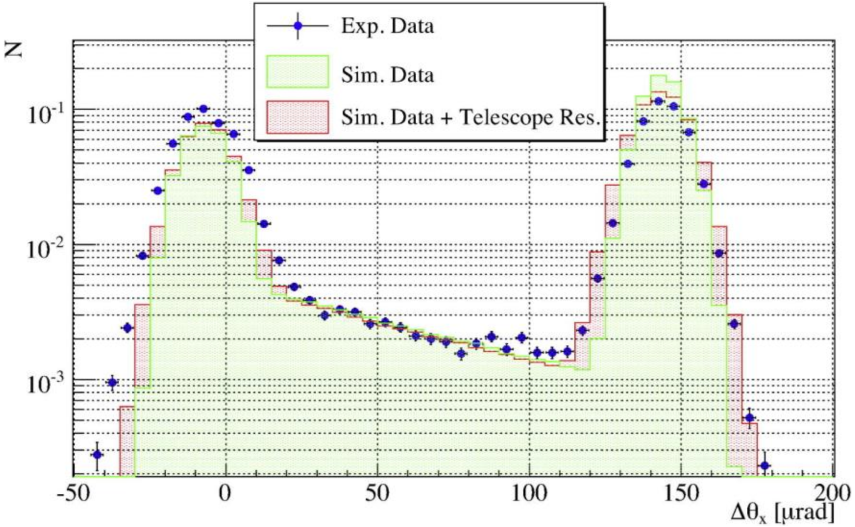
**Number of particles within ±3σ: 4520869**

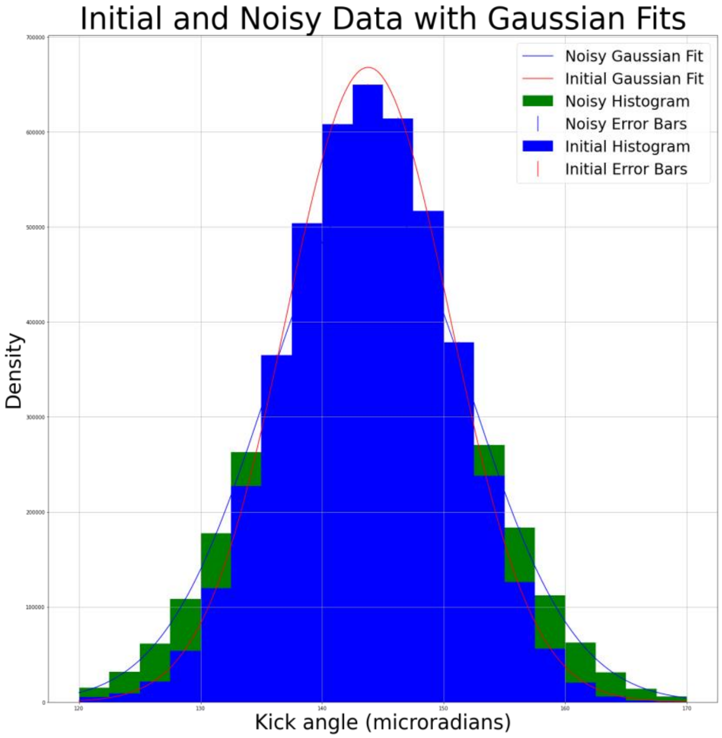
**Channelling Efficiency: 66.2%**



# Conclusions

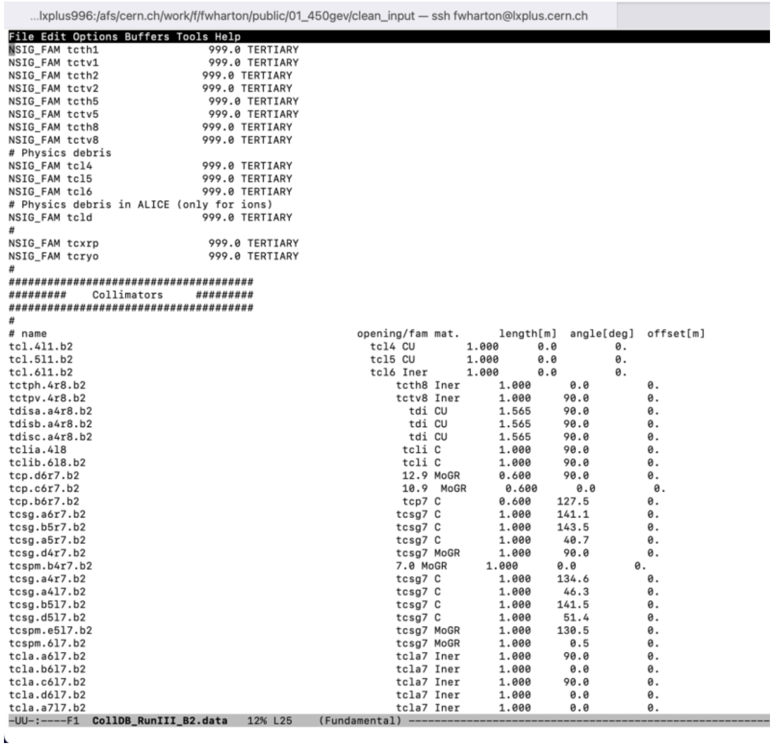
I found that the results of my simulation analysis match up well with results from a corresponding NDC paper, which validates this simulation tool and my analysis script for this MD.



# Next Steps

- I am currently using SixTrack to simulate a test of a TCPC crystal in the LHC.
  - I have completed the first simulation using particles at 450 GeV and will repeat the process considering crystal channeling at higher energies of 1 TeV, 3 TeV, and 5 TeV.
- Using the analysis script described here to find the channeling efficiency at each energy, so it can be compared to the collected data from the MD measurements.



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...lxplus996:/afs/cern.ch/work/f/fwharton/public/01_450gev/clean_input — ssh fwharton@lxplus.cern.ch
File Edit Options Buffers Tools Help
NSIG_FAM tcth1                 999.0 TERTIARY
NSIG_FAM tctv1                 999.0 TERTIARY
NSIG_FAM tcth2                999.0 TERTIARY
NSIG_FAM tctv2                999.0 TERTIARY
NSIG_FAM tcth5                 999.0 TERTIARY
NSIG_FAM tctv5                 999.0 TERTIARY
NSIG_FAM tcth8                999.0 TERTIARY
NSIG_FAM tctv8                999.0 TERTIARY
# Physics debris
NSIG_FAM tcl4                 999.0 TERTIARY
NSIG_FAM tcl5                 999.0 TERTIARY
NSIG_FAM tcl6                 999.0 TERTIARY
# Physics debris in ALICE (only for ions)
NSIG_FAM tcld                 999.0 TERTIARY
#
NSIG_FAM tcxrp                 999.0 TERTIARY
NSIG_FAM tcryo                 999.0 TERTIARY
#
######################################
#########    Collimators     #########
######################################
#
# name                                                   opening/fam mat.      length[m]  angle[deg]  offset[m]
tcl.4l1.b2                                                 tcl4 CU       1.000      0.0         0.
tcl.5l1.b2                                                 tcl5 CU       1.000      0.0         0.
tcl.6l1.b2                                                 tcl6 Iner     1.000      0.0         0.
tctph.4r8.b2                                                   tcth8 Iner      1.000       0.0         0.
tctpv.4r8.b2                                                   tctv8 Iner      1.000      90.0         0.
tdisa.a4r8.b2                                                    tdi CU        1.565      90.0         0.
tdisb.a4r8.b2                                                    tdi CU        1.565      90.0         0.
tdisc.a4r8.b2                                                    tdi CU        1.565      90.0         0.
tclia.4l8                                                       tcli C         1.000      90.0         0.
tclib.6l8.b2                                                    tcli C         1.000      90.0         0.
tcp.d6r7.b2                                                     12.9 MoGR      0.600      90.0         0.
tcp.c6r7.b2                                                     10.9  MoGR      0.600       0.0         0.
tcp.b6r7.b2                                                     tcp7 C         0.600     127.5         0.
tcsg.a6r7.b2                                                   tcsg7 C         1.000     141.1         0.
tcsg.b5r7.b2                                                   tcsg7 C         1.000     143.5         0.
tcsg.a5r7.b2                                                   tcsg7 C         1.000      40.7         0.
tcsg.d4r7.b2                                                   tcsg7 MoGR      1.000      90.0         0.
tcspm.b4r7.b2                                                  7.0 MoGR      1.000      0.0         0.
tcsg.a4r7.b2                                                   tcsg7 C         1.000     134.6         0.
tcsg.a4l7.b2                                                   tcsg7 C         1.000      46.3         0.
tcsg.b5l7.b2                                                   tcsg7 C         1.000     141.5         0.
tcsg.d5l7.b2                                                   tcsg7 C         1.000      51.4         0.
tcspm.e5l7.b2                                                  tcsg7 MoGR      1.000     130.5         0.
tcspm.6l7.b2                                                   tcsg7 MoGR      1.000       0.5         0.
tcla.a6l7.b2                                                   tcla7 Iner      1.000      90.0         0.
tcla.b6l7.b2                                                   tcla7 Iner      1.000       0.0         0.
tcla.c6l7.b2                                                   tcla7 Iner      1.000      90.0         0.
tcla.d6l7.b2                                                   tcla7 Iner      1.000       0.0         0.
tcla.a7l7.b2                                                   tcla7 Iner      1.000       0.0         0.
-UU-:----F1  CollDB_RunIII_B2.data   12% L25    (Fundamental) ----------------------------------------
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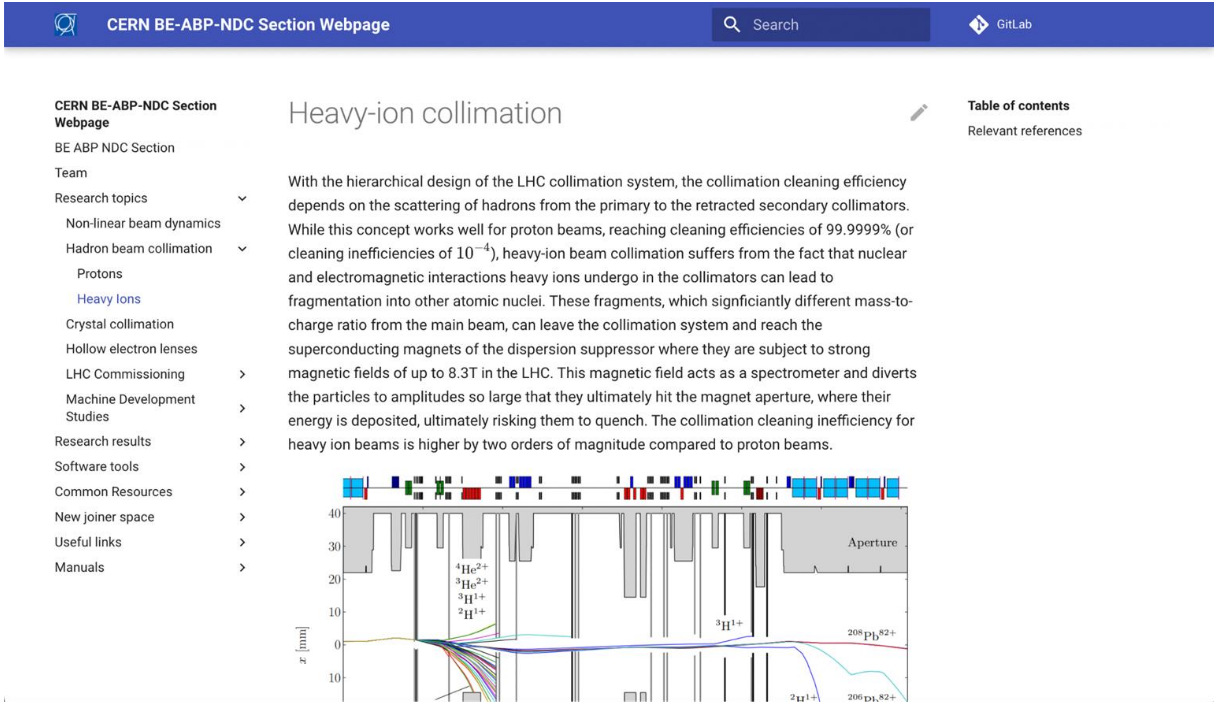
# Updates to the NDC section website


CERN BE-ABP-NDC Section Webpage

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GitLab



## Heavy-ion collimation

With the hierarchical design of the LHC collimation system, the collimation cleaning efficiency depends on the scattering of hadrons from the primary to the retracted secondary collimators. While this concept works well for proton beams, reaching cleaning efficiencies of 99.9999% (or cleaning inefficiencies of $10^{-4}$), heavy-ion beam collimation suffers from the fact that nuclear and electromagnetic interactions heavy ions undergo in the collimators can lead to fragmentation into other atomic nuclei. These fragments, which signficiantly different mass-to-charge ratio from the main beam, can leave the collimation system and reach the superconducting magnets of the dispersion suppressor where they are subject to strong magnetic fields of up to 8.3T in the LHC. This magnetic field acts as a spectrometer and diverts the particles to amplitudes so large that they ultimately hit the magnet aperture, where their energy is deposited, ultimately risking them to quench. The collimation cleaning inefficiency for heavy ion beams is higher by two orders of magnitude compared to proton beams.